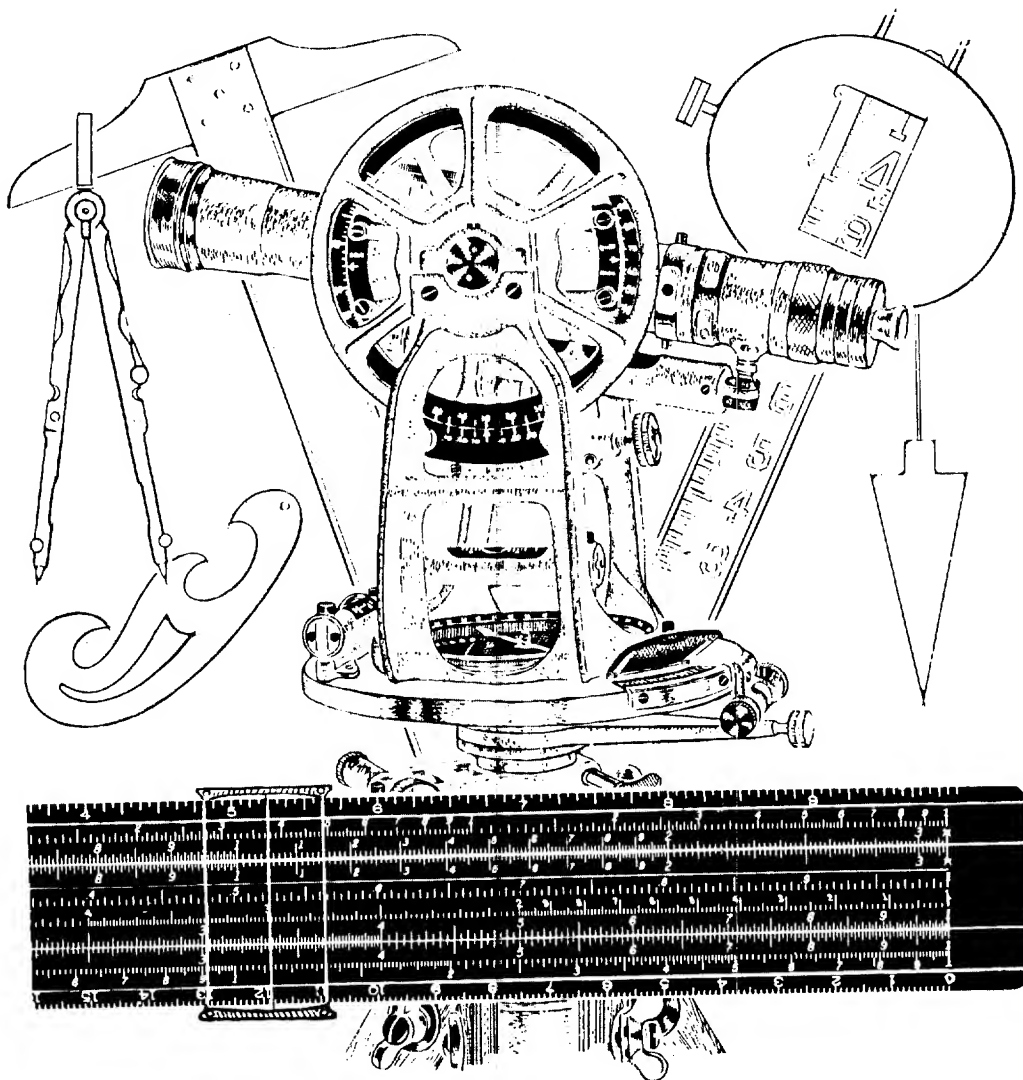


*NAVY's "Seabees" use SHALLOW SEISMOLOGY
— Here are excerpts from their manual.*



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BUREAU OF NAVAL PERSONNEL

RATE TRAINING MANUAL

NAVPERS 10635-A

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Disturbed and Undisturbed Samples

"Disturbed" samples are samples taken by hand scoops, shovels, auger borings, or wash borings. No attempt is made to obtain the material in its natural state of structure or density.

"Undisturbed" samples are taken by samplers when it is desired to know the natural or in-place density of the soil stratum, the shear strength, and the compressive strength.

Quartering a Sample

A disturbed sample is reduced to a smaller, more manageable size for testing by the procedure called "quartering." The procedure is followed to ensure that the smaller portion will be representative of the whole sample.

The sample is first thoroughly mixed, then poured out on a canvas and spread into a circular layer of uniform thickness. The layer is divided into quarters by cutting two diameters through it at right-angles to each other, just as you would cut a pie into four equal wedges. Two diagonally opposite quarters are discarded. The remaining two are combined, taking care to include all dust and fines. The process is then repeated, until the sample residue has been reduced to the size desired.

For sandy soil a "sample splitter" or "riffler" may be used to reduce the size of the sample. The splitter divides the sample into halves; by repeating the operation, you get quarters, eighths, sixteenths, and so on.

Through the use of the various types of published information and air photographs, the exploration of a general area may be narrowed down to several smaller areas suitable for further investigation. The extent and method of collecting more detailed information by field observations will depend on the time available.

Rapid ground observation, along the proposed highway or airfield location, may yield valuable information when circumstances do not permit a complete or deliberate soil survey. The soil profile may be observed along the natural banks of streams, eroded areas, bomb craters, road cuts, or other places where the stratification is exposed. Such observations may indicate types of soil and depths of layers. Loose surface soil should be scraped off before the examination and field identification are made. Samples may be taken from exposed soils for testing in a field laboratory; however, sampling and testing are normally a minimum in this type

of soil survey. Surface soils may be exposed by the use of pick and shovel, particularly in areas of questionable soils or at critical points in the location. Soils identified in the hasty survey may be located by field sketches or on available maps or photographs.

A deliberate investigation is made when time and equipment are available and when a more thorough investigation of the sub-soil is needed than can be obtained by hasty field observations. The two most commonly used methods of obtaining soil samples for deliberate investigations are **TEST PITS** and **TEST HOLES**.

A third method of investigation, which reveals information about the sub-soil structure, is the **SEISMIC SURVEY**, described later in this chapter.

A test pit is an open excavation which is large enough for a man to enter and study the soil in its undisturbed condition. This method provides the most satisfactory means for observing the natural condition of the soil and the collection of undisturbed samples. The test pit is usually dug by hand, but power excavation by dragline, clamshell, bulldozer, backhoe, or a large 24-in. diameter power-driven earth auger can expedite the digging—if the equipment is available. Excavations below the ground water table require the use of pneumatic caissons or the lowering of the water table. Load bearing tests can also be performed on the soil in the bottom of the pit.

The use of the hand auger is the most common method of digging test holes. It is best suited to cohesive soils but can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. By adding a pipe extension, the earth auger may be used to a depth of about 30 ft in relatively soft soils. The sample is completely disturbed but is satisfactory for determining the soil profile, classification, moisture content, compaction capabilities, and similar properties. Auger borings are principally used for work at shallow depths.

WASH BORING is probably the most common method used commercially to make deep test holes in all soil deposits except rock or other large obstructions. The test hole is made by a chopping bit fastened to a wash pipe inside a 2-, 4-, or 6-in. diameter steel casing. The wash pipe is churned up and down while the bit from which water flows under pressure loosens the soil. The water then carries the soil particles

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to the surface, where they are collected inside the casing. An experienced operator can detect from the appearance of the wash water when a change in the type of soil being penetrated has occurred. Wash samples are samples taken directly from the wash water; they are so disturbed, however, that their value is limited. They should not be used unless no other means is available.

DRY-SAMPLE boring makes use of the wash boring method to sink the hole. When a change of soil type occurs, or sometimes at specified depth intervals, the washing is stopped and the bit is replaced by a SAMPLER. The sampler, an open-end pipe, is driven into the relatively disturbed soil in the bottom of the hole to extract a sample. The sample is removed and preserved in a sample bottle until tested in the laboratory.

The UNDISTURBED SAMPLING process is used to obtain samples with negligible disturbance and deformation for testing for shear strength, compressibility, and permeability. Special samplers are used for this purpose. To minimize the amount of disturbance, they must be jacked gradually into the ground, with twisting or jarring carefully avoided. These samples can best be obtained from relatively cohesive soils.

The CORE BORING process is used to obtain samples from boulders, sound rock, frozen ground, and highly resistant soils. The cutting element may consist of diamonds, chilled shot, or steel-tooth cutters. The drill cuts an angular ring in the rock, leaving a central core which enters the drill's CORE BARREL and is retained by a holding device when the drill is removed from the hole. This is the best method for determining the characteristics and condition of subsurface rock.

The SEISMIC SURVEY is made from the ground surface, using the MODEL R-117B SEISMIC TIMER. This method gives information about the depth of soil, and about the thickness and dip of subsurface layers of rock or other dense materials. Seismic survey data is often useful in planning the best location for test pits and test holes. It is also useful in extending test hole information over a large site area. The method is described later.

PLANNING FIELD EXPLORATIONS

The location of test holes or test pits will depend upon the particular situation. In any case, since soil tests should be made on samples

which are representative of the major soil types in the area, the first step in exploration is to develop a general picture of the subgrade conditions to assist in determining the representative soils. Field reconnaissance should be made to study land forms and soil conditions in ditches

and cuts. Seismic surveys should be made to detect the presence of subsurface HORIZONS of layered materials or bedrock, and the depths to such materials. Techniques have been developed whereby aerial photographs can be used for delineating areas of similar soil conditions. Full use should be made of all existing data.

Subgrade Areas

To determine subgrade conditions in an area to be used for road or for airport runway, taxiway, and apron construction, the next step after field reconnaissance is usually the making of preliminary borings at strategic points.

An arbitrary spacing of these borings at uniform intervals does not give a true picture and is not recommended. Intelligent use of various procedures, especially the seismic survey and the technique of locating soil boundaries from aerial photographs, will permit strategic spacing of the preliminary borings to obtain maximum information with a minimum number of borings.

Soil samples should be obtained for classification purposes in these preliminary borings. After these samples are classified, soil profiles should be developed. Additional seismic surveys can be made, as required, to assist in extending soil profile lines where no preliminary borings exist. Representative soils should then be selected for detailed testing. Test pits or larger-diameter borings should then be made to obtain the samples needed for testing, or to permit in-place tests to be made. The types and number of samples required will depend on the characteristics of the subgrade soils. Sub-soil investigations in areas of proposed pavement must include measurements of in-place water content, density, and strength, to determine the depth to which compaction must extend and to ascertain whether soft layers exist in the subsoil.

Borrow Areas

When material is to be borrowed from adjacent areas, borings carried 2 to 4 ft below the anticipated depth of borrow should be made

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CLAYEY SOILS: The clay grains are not at all gritty, but feel smooth and powdery like flour between the teeth. Dry lumps of clayey soils will stick when lightly touched with the tongue.

SLAKING TEST

The slaking test is used to assist in determining the quality of certain soft shales and other soft "rocklike" materials. The test is performed by placing the soil in the sun or in an oven to dry, and then allowing it to soak in water for at least 24 hours. The strength of the soil is then examined. Certain types of shale will completely disintegrate, losing all strength.

ACID TEST

The acid test is used to determine the presence of calcium carbonate and is performed by placing a few drops of hydrochloric acid on a piece of soil. A fizzing reaction (effervescence) to this test indicates the presence of calcium carbonate, and the degree of reaction gives an indication of the concentration. Calcium carbonate normally is desirable in a soil because of the cementing action it provides to add to the stability. (In some very dry noncalcareous soils, the absorption of the acid creates the illusion of effervescence. This effect can be eliminated in all dry soils by moistening the soil prior to applying the acid.) Since this cementation normally is developed only after a considerable curing period, it cannot be counted upon for strength in most military construction. The primary use for this test is, therefore, to permit better values on fine-grained soils which are tested in-place, where this property may exert considerable influence.

SHINE TEST

The shine test is another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay will give a definite shine when rubbed with a finger nail, a pocket knife blade, or any smooth metal surface. On the other hand, a piece of lean clay will not display any shine, but will remain dull.

FEEL TEST

The feel test is a general purpose test, and one that requires considerable experience and

practice before reliable results can be obtained. The extent of its use will grow with increasing familiarity with soils. Consistency and texture are two characteristics which can be determined.

The natural moisture content of a soil is of value as an indicator of the drainage characteristics, nearness to water table, or other factors which may affect this property. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. The consistency is described by such terms as "hard," "stiff," "brittle," "friable," "sticky," "plastic," or "soft." The soil is then remolded by working it in the hands, and changes, if any, are observed. By this test, the natural water content is estimated relative to the liquid or plastic limit of the soil. Clays which turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff, and crumbles upon being remolded, the natural water content is below the plastic limit.

The term "texture," as applied to the fine-grained portion of a soil, refers to the degree of fineness and uniformity. It is described by such expressions as "floury," "smooth," "gritty," or "sharp," depending upon the sensation produced by rubbing the soil between the fingers. Sensitivity to this sensation may be increased by rubbing some of the material on a more tender skin area such as the wrist. Fine sand will feel gritty. Typical dry silts will dust readily, and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

SEISMIC SURVEYING

Seismic surveying is a geophysical technique, used for many years in the study of deep geological structure, such as in the search for oil-bearing strata. It is based on the measurement of shock waves in the earth. More recently, the method has been greatly simplified for use in shallow (0 to 100-feet deep) investigations of soils and related geology. These depths are of interest to engineers who must obtain soil and rock profiles for road construction, airport design, pipeline routes, damsites, large building foundations, site grading, waterfront structures and similar projects. They are also important in the study of groundwater sources, underground drainage, and the location of rock sources for quarrying concrete aggregates.

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SHALLOW SEISMIC SURVEYING has become a reliable, fast and economical method for obtaining sub-surface soil and rock profiles, due to the development of portable, self-powered SEISMIC TIMERS, such as the MODEL R-117B, and its accessory equipment. The instrument can be carried over any terrain, and operated by a two-man party. Instead of the large explosive charges and elaborate recording equipment used in deep seismic work, most of the shallow seismic surveying is accomplished by using an eight-pound sledge hammer and a small steel strike plate to produce shock waves in the earth. The travel-times of these shock waves, from the impact point to a GEOPHONE, are measured with the SEISMIC TIMER. A complete discussion of the theory and field methods of shallow seismic surveying is given in the instruction manual for the R-117B Seismic Timer. Personnel assigned to conduct seismic surveys must be those who have received special training in the method. However, personnel holding EA1 and EAC ratings should be generally familiar with the applications and objectives of shallow seismic surveying. For that reason, the essential features of the method are presented here.

PRINCIPLES OF SEISMIC SURVEYING

An explosion in the ground, or the impact of a heavy weight on the ground, produces disturbances in the earth, similar to the "sound waves" produced in the air. These disturbances are called ELASTIC WAVES. These waves travel out in all directions from the impact point. Their energy is of course gradually absorbed by the earth, so that their effect for practical purposes eventually dies out. But over the first part of their path, they can be detected and used to determine earth structure. In uniform soils, the waves travel along straight paths, from the source. The WAVE FRONT is thus an ever-expanding spherical surface.

Travel-Time and Wave Velocity

In seismic surveying, an instrument called a GEOPHONE (item 5, fig. 11-33) is used to detect the arrival of the wave front at a desired point on the ground surface. The waves are created in the earth by the impact of an eight-pound sledge hammer (item 2, fig. 11-33) on a STRIKE PLATE (item 3). The strike plate is placed on firm topsoil at the IMPACT POINT.

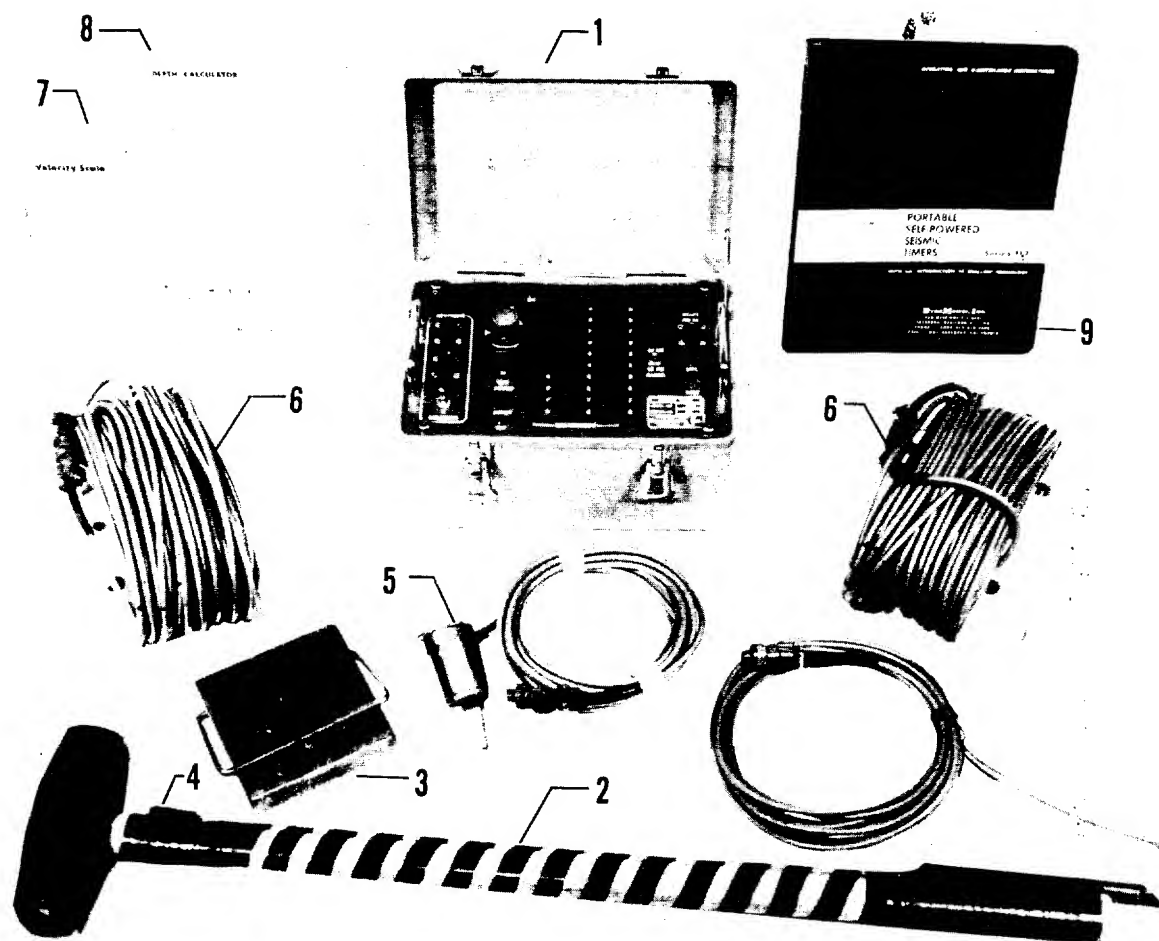
When the hammer strikes the plate, a SHOCK SWITCH (item 4) on the hammer sends a START signal to the seismic timer (item 1). The geophone is located at a point on the ground some distance away from the impact point, as explained later. When the leading edge of the wave front reaches the geophone, the geophone sends a STOP signal to the timer. The time for the wave to travel from the impact point to the geophone is indicated on the instrument panel. The seismic timer is the equivalent of a precision high-speed stop watch. It measures TRAVEL TIMES.

If hammer impacts are made at a series of impact points along the SEISMIC SURVEY LINE, the travel-times from each impact point to a geophone at the beginning of the line can be measured. At each impact station, the travel-time is plotted, to make a TRAVEL-TIME GRAPH (fig. 11-34). The time unit used for measurement is the millisecond. One millisecond is .001 second. The distance unit used for measurement along the survey line is the foot. Impact stations are usually 10 feet apart. The scale of the travel-time graph used for work in soils is one millisecond (vertical) equals one foot (horizontal). The graph paper is divided into 1-inch x 1-inch major squares, with ten divisions per inch. Thus, one inch equals ten feet or ten milliseconds.

If the soil is uniform for a considerable depth, the plotted travel times will make a straight line travel-time graph (fig. 11-34). The distance along any portion of this line, divided by the increase in travel-time for that portion of the line, gives the wave velocity, in feet per second. In the example shown, the distance between impact stations 10-ft and 40-ft, is 30 feet. The time difference between travel from station 10-ft and travel from station 40-ft, is 25 milliseconds (.025 sec.). Therefore, the velocity at which the elastic wave is traveling through the soil is 30 feet divided by .025 sec, or 1,200 feet-per second. This is a typical velocity for topsoil.

Remember then, that the VELOCITY is indicated by the slope of the travel-time graph over a straight portion. A VELOCITY SCALE, provided with the instrument, allows velocities to be read directly from the plotted graph. The flatter the slope, the higher the velocity. On 10 x 10 graph paper, a slope of 45° (one to one) indicates a velocity of 1,000 feet-per second. Velocities in the subsurface materials are one of the two pieces of information needed

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- | | |
|----------------------------------|--|
| 1. Model R-117B seismic timer | 6. Cable, 150-ft, shielded |
| 2. Seismic sledge hammer | 7. Velocity scale |
| 3. Strike plate | 8. Depth calculator |
| 4. Shock switch for start signal | 9. Operation and maintenance instruction |
| 5. Geophone | |

Figure 11-33.—Model R-117B Seismic Timer and accessories.

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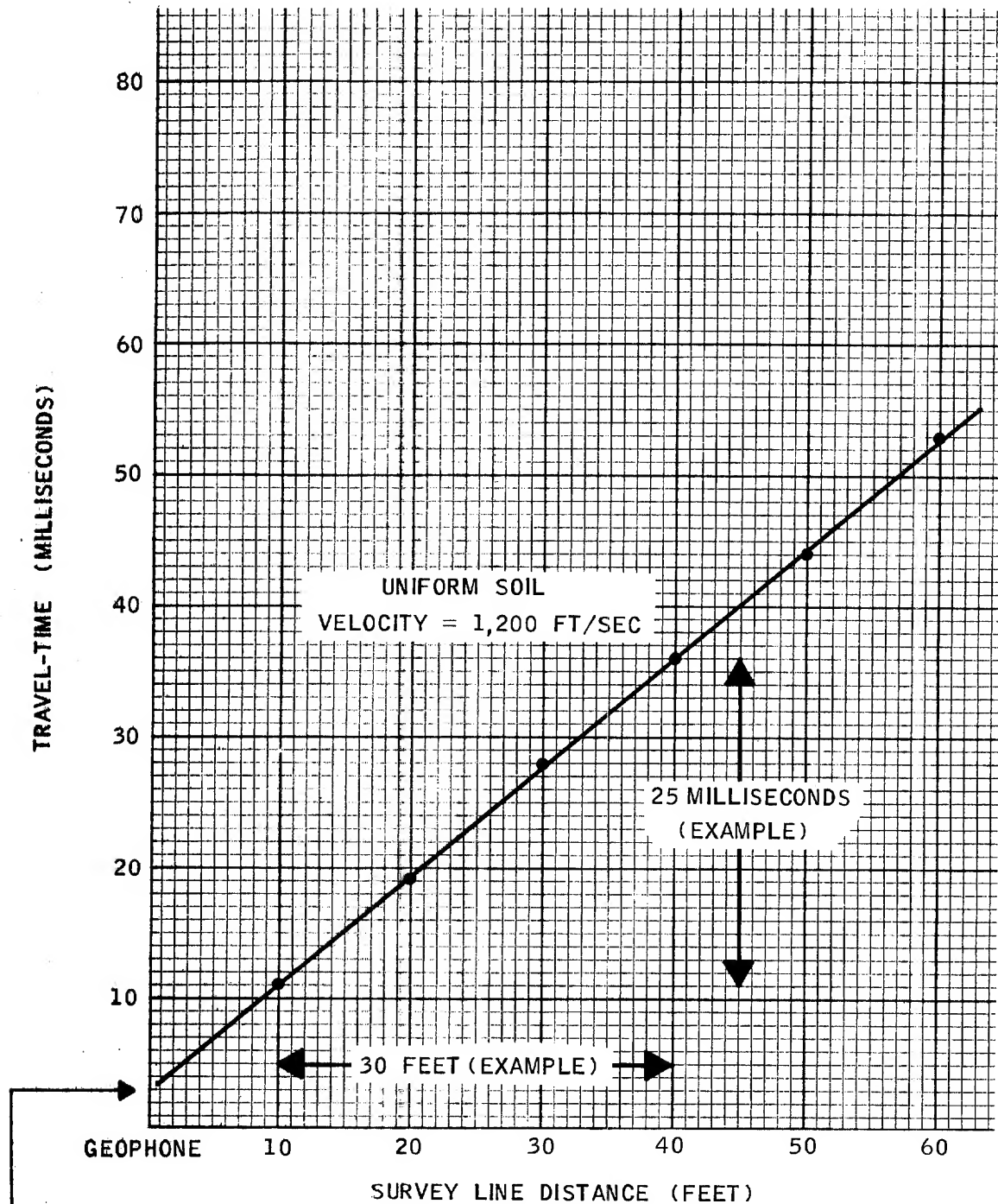
to discover subsurface layers and find their depth below ground surface.

Subsurface Horizons and Seismic Refraction

So far, we have considered only the case of uniform soil. Now let us see what happens to the wave path when the expanding wave front encounters a subsurface layer of material different from the top soil. This situation is shown in figure 11-35.

When the elastic waves encounter a subsurface HORIZON (top of a new layer of different material) the direction of the wave paths is changed. This change in direction is called REFRACTION. It is the same thing that happens when light rays enter a lens or a prism, or the smooth surface of water, at an angle with the surface. Remember how a pencil appears to bend when inserted in a glass of water. A similar thing happens when ocean waves encounter a headland at an angle, they are bent toward the shoreline.

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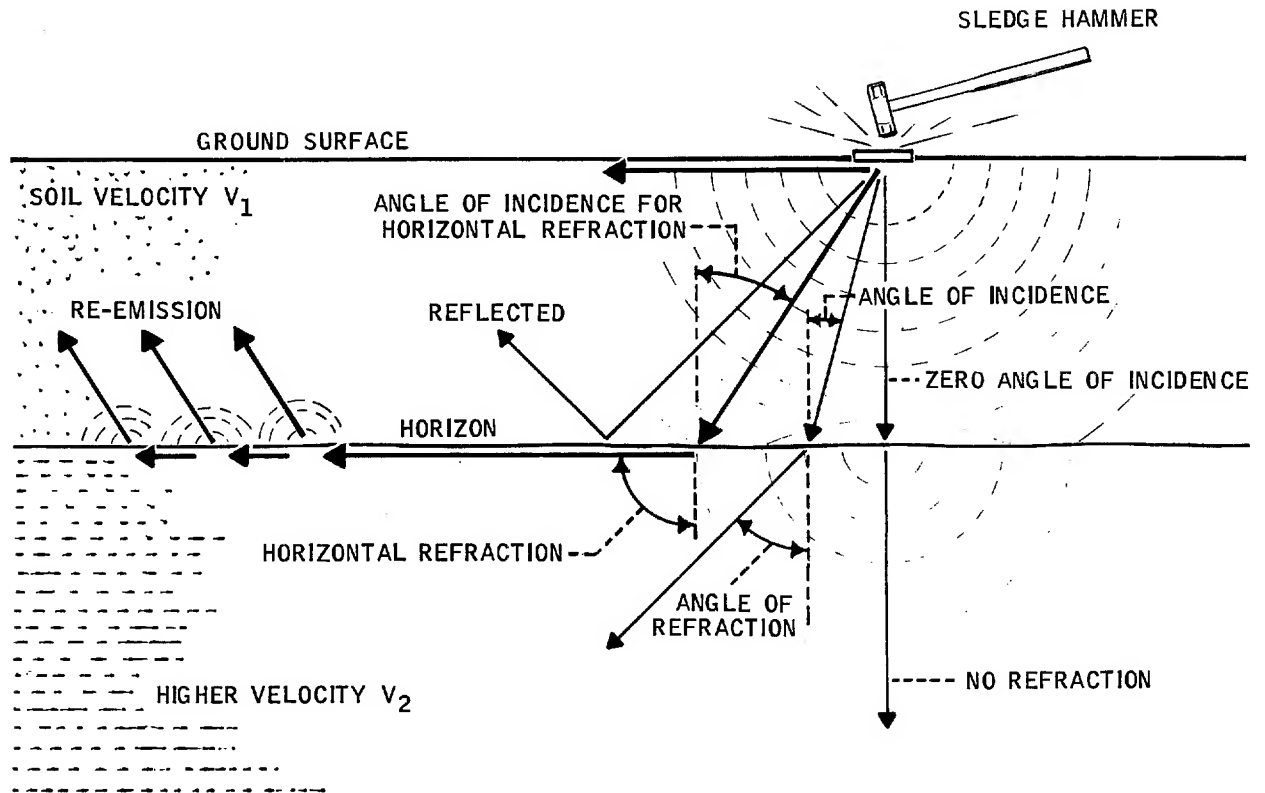


NOTE - Graph usually does not cross at zero, due to slight delays at strike plate and geophone. This does not affect results of survey.

Figure 11-34.—Travel-time graph, uniform soil.

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Figure 11-35.—Elastic wave paths at a subsurface horizon.

Refraction is caused by a change in wave velocity, in passing from one material into another. Wave paths that enter straight (perpendicular to the interface) are not bent at all. Wave paths that enter at an angle (called the **ANGLE OF INCIDENCE**) are bent, more and more as the angle becomes sharper. When the angle becomes sharp enough, the wave path will not enter the second material, but will be **REFLECTED** from the surface, rather than refracted.

For any particular angle of incidence, the amount of bending, or refraction, depends on the velocities in the two materials. If the velocities are almost the same, very little bending will occur. If the velocities are greatly different, a great deal of bending will take place.

In the case of light entering a glass lens or prism, the velocity in the second material (glass) is lower than the velocity of light in air.

So the light waves are bent **TOWARD** the perpendicular (into the glass). This case is not applicable to seismic refraction, since the elastic waves would be bent downward, into the earth, and not return to the surface. For this reason, seismic refraction cannot discover layers of soil having lower velocities than the overlying materials. Fortunately, in almost every case, the lower materials, being more compacted, have higher velocities.

When the elastic waves enter a subsurface horizon of a higher velocity material, they are bent **AWAY** from the vertical. At one particular angle of incidence, the wave path will be bent enough to travel right along the surface of the horizon, parallel to the interface. It is this wave path that makes seismic refraction surveying possible.

As the refracted, horizontal wave travels along in the higher velocity material, it

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constantly gives off energy in all directions. Some of this energy returns to the ground surface, along a path at the same angle that the wave entered the refracting horizon. This energy eventually reaches the geophone.

We now have two different paths which the elastic waves can take to reach the geophone from any impact point. The DIRECT PATH is through the top soil to the geophone. It travels at the velocity of the top soil, V_1 . The REFRACTED PATH is down through the top soil at some angle, traveling at velocity V_1 , then along the subsurface horizon at velocity V_2 , then back up to the geophone at velocity V_1 . The two paths are shown in figure 11-36.

First-Arrival Refraction Surveying

The geophone is placed at the beginning (zero) end of the survey line. The hammer man moves out along the line, making impacts at each 10-ft station. The instrumentman measures the travel-time of the FIRST ARRIVAL of elastic wave energy at the geophone, since it is the first-arrival which stops the timer. The resulting travel-time graph is shown in figure 11-37. When the impacts are close to the geophone, the shortest travel time is directly through the top soil, as in the example for uniform soil (fig. 11-34). However, at some point along the survey line, because of the faster

velocity in the second layer, the first-arrivals of the direct path and for the refracted path will be the same. And at all points beyond that point, the refracted path will give the shorter travel time. This point where the two travel-time graphs intersect is called the CRITICAL POINT. The distance from the geophone to the critical point is called the CRITICAL DISTANCE (Symbol, L).

The critical distance is important because at this distance, THE TRAVEL TIMES over both the DIRECT and the REFRACTED path are the SAME. The depth determination formula is based on this fact. Derivation of the formula can be found in any standard geophysics text.

The velocity V_1 , in the first layer, is taken from the first portion of the travel-time graph. The velocity in the second layer, V_2 , is taken from the second portion of the travel-time graph. The critical distance, L_1 (in this case, $L_1 = L$ in fig. 11-37) is shown on the graph because it is the distance to the point where the first travel-time curve "breaks" to the second travel-time curve.

Seismic refraction surveying is not limited to the case of two layers. For each successive, higher-velocity layer, a new portion of the travel-time curve will be observed, each at a flatter slope (higher velocity) and at a new critical distance, L_2 , L_3 , and so on. All critical distances are measured from the beginning of the survey line.

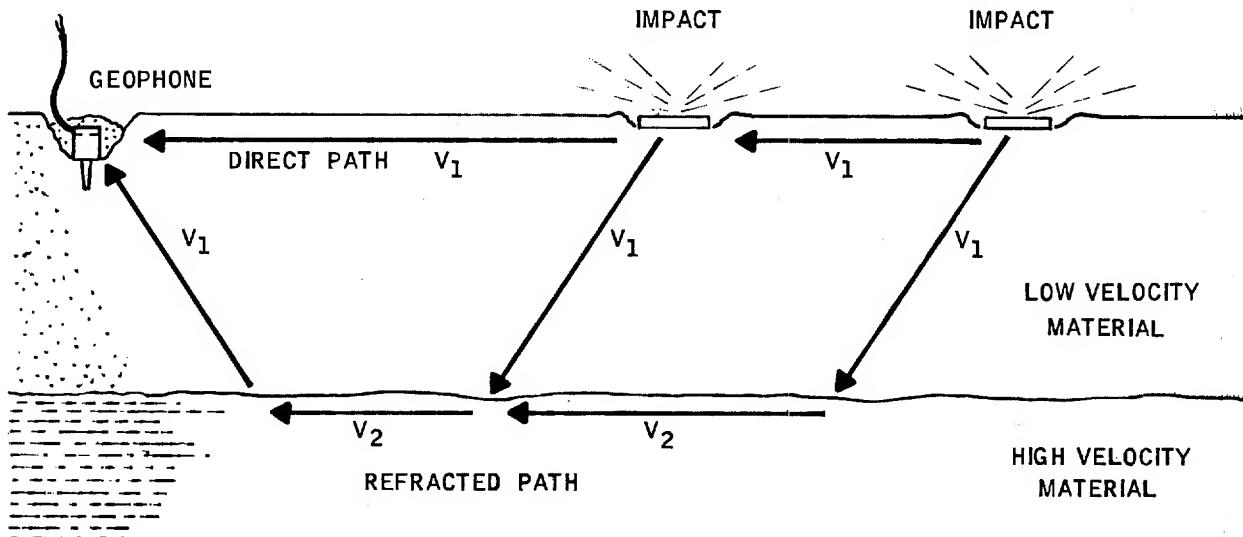


Figure 11-36.—Direct and refracted elastic wave paths.

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Determination of Depth to Successive Horizons

The critical distances are the second piece of information needed to determine depth of subsurface horizons. Calling the depth to the first subsurface horizon (top of second layer) " d_1 ", the formula is:

$$d_1 = \frac{L_1}{2} \sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

It is not necessary to work out the mathematics to find the depth. A depth calculator nomograph, provided with the instrument, solves the problem. The critical distance L_1 is taken from the travel-time graph. The velocities V_1 and V_2 are read from the graph by using the VELOCITY SCALE, which is a transparent overlay.

In the same manner, by observing critical distances and velocities on the travel-time graph, and by using the depth calculator, the depths to successively deeper layers of material can be determined. If the layers do not lie parallel to the ground surface, they are said to have an APPARENT DIP with respect to the ground surface. This is detected when a geophone is placed at each end of the survey line (DOUBLE-HEADED LINE) and two travel-time graphs are plotted, one from each end of the line. For this reason, double-headed lines are used whenever possible. The seismic timer has provision for two geophone inputs, with a geophone selector switch. The hammer man moves down the survey line only once, but by switching from GEOPHONE 1 to GEOPHONE 2, the instrumentman can obtain travel-times to both geophones from each impact station. The survey line is normally 150 feet long. A double-headed travel-time graph is shown in figure 11-38.

A complete discussion of shallow seismic surveying is beyond the scope of this text. Personnel qualified as seismic surveyors are trained, using the R-117B, the instruction manual, and additional reference material. The present discussion is intended to give general familiarity with the method, for supervisory personnel and those interested in further study.

SEISMIC SURVEY FIELD PROCEDURES

In general, the field procedure for making a seismic survey consists of the following:

(a) Locate the desired seismic survey lines on a map or plan of the area. If possible, this should be a topographic map showing the ground surface contours.

(b) Lay out the seismic survey lines in the field and conduct the seismic surveys. Wherever possible, the survey lines should be double-headed, using a geophone at each end of the line. Plot the travel-time data directly on field seismic survey data sheets, so that the graphs are available as the work progresses.

(c) In the office, using the field data, replot the travel-time graphs on profile paper. Calculate the various depths to subsurface materials and their apparent dips relative to ground surface, if any. Plot the subsurface soils profile directly above the corresponding travel-time graphs, noting all discontinuities, dips and other features encountered. Correlate the profile with other data, such as observed surface outcrops and information from any test pits or borings adjacent to the survey site.

(d) Show the location of the constructed soil profile line on the area topographic map.

These procedures are discussed in more detail in the following paragraphs.

Planning the Seismic Survey

The exact location of the seismic survey lines will depend on the purpose of the survey (site or airport grading, road cut, heavy foundation construction, quarry location, and so on). The locations should be decided after discussion with the engineer in charge of the work. Indicate the location of each seismic line on the area topographic map or plan as shown in figure 11-39. A heavy black line indicates the survey line, with a solid black dot at each geophone location. Number the tracks, and number the geophone locations with a track number followed by the letter A or B. In figure 11-39, survey lines have been located for a single airstrip profile, a beach-head profile, and a search for rock materials at the foot of the rolling hills to the north of the base. The location of seismic track 2, at the Quarry site and its geophones, A and B, are shown on figure 11-39. The seismic data is shown in figure 11-38. Note, also, the seismic checks made on shale and gravel outcrops at the Quarry site.

As the seismic surveys progress, additional survey lines may be added where necessary to clarify a subsurface situation or continue an exploration line.

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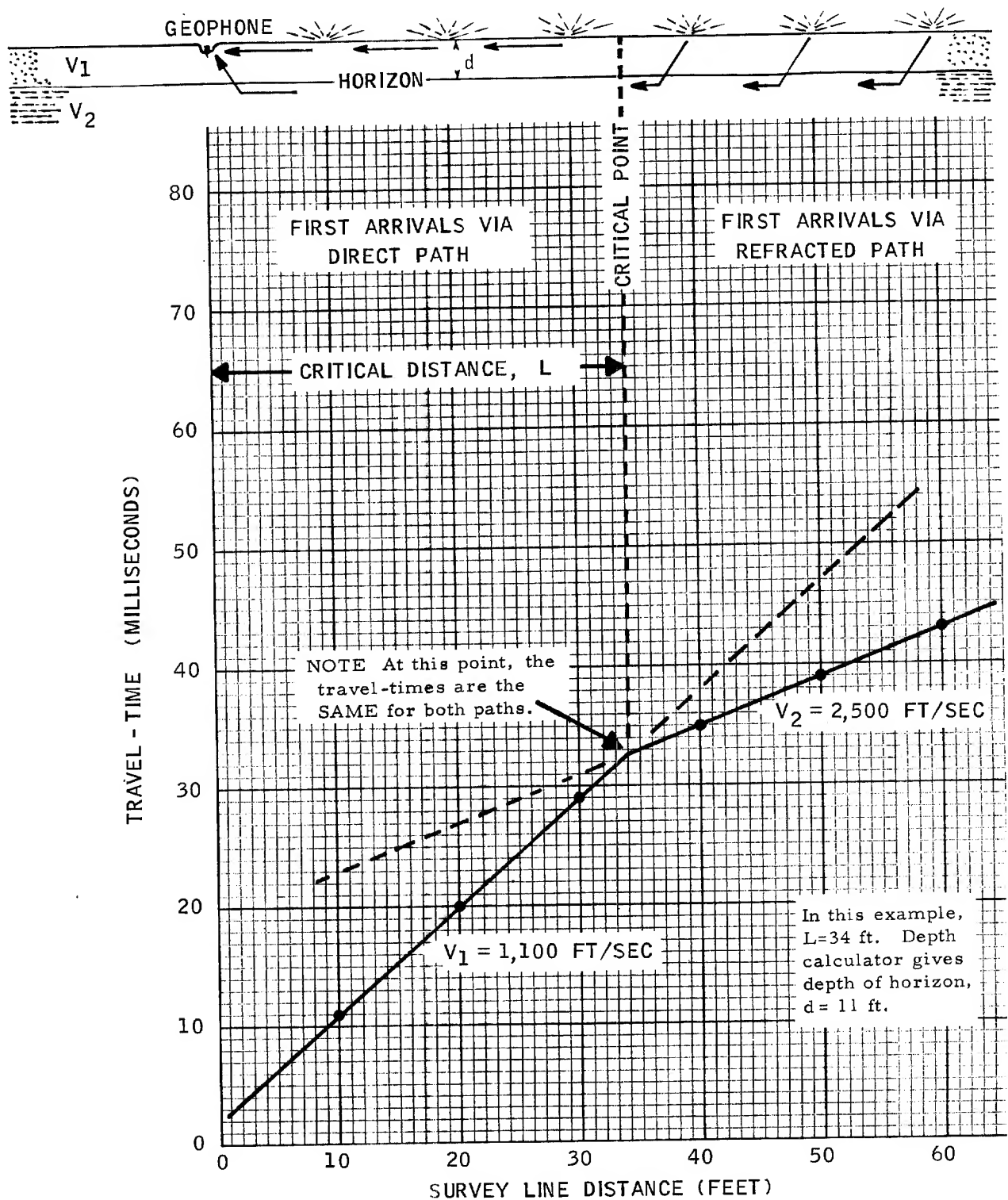
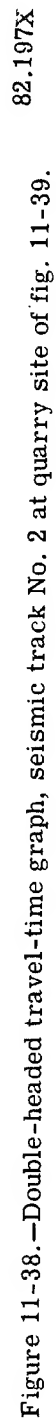


Figure 11-37.—Travel-time graph showing discovery of a subsurface horizon.

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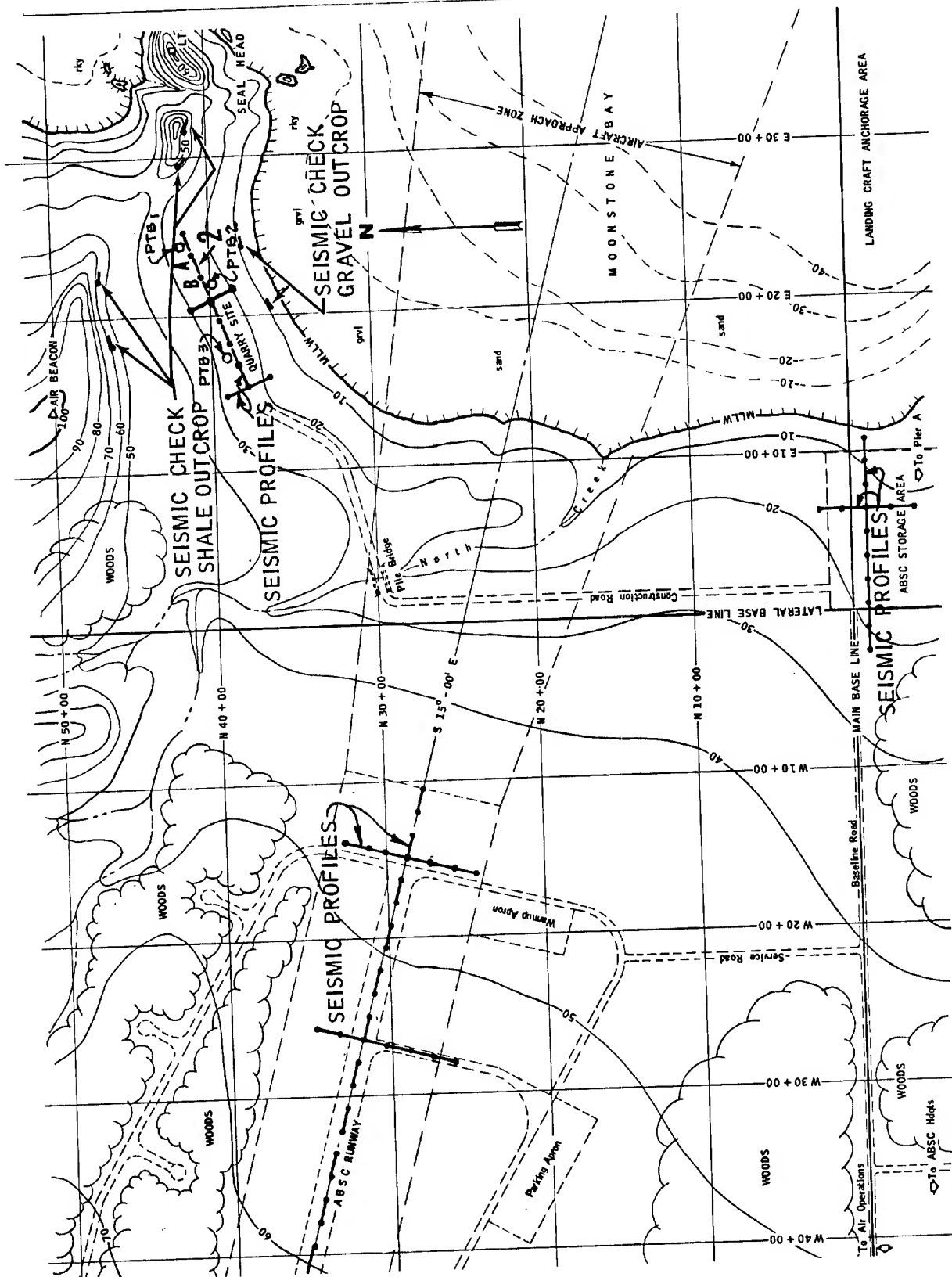


Figure 11-39.—Area topographic map, showing seismic survey lines.

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Making the Seismic Survey

The detailed, step-by-step procedure for the seismic survey is given in the instruction manual for the R-117B Seismic Timer. In general, the procedure is as follows:

(a) Hammerman and instrumentman lay out 150-foot survey line, using 1/4-inch yellow polyethylene survey line marked at 10-foot stations with black tape.

(b) Plant geophone at each end of the line. Clear away any loose top material or grass. Dig a 6-inch to 8-inch hole. Press geophone spike firmly into ground. Cover geophone with

loose soil and stand firmly on top to make good coupling between geophone and ground. If soil is very dry, add a little moisture to get firm compaction.

(c) Connect both geophones to the input connectors on the seismic timer, using one of the 150-foot cables for the geophone at the far end of the line. The field set-up is shown in figure 11-41.

(d) Connect the sledge hammer to the seismic timer. It can be directly connected by cable, or it can be connected using the R221 RADIO LINK (fig. 11-40) as explained in the

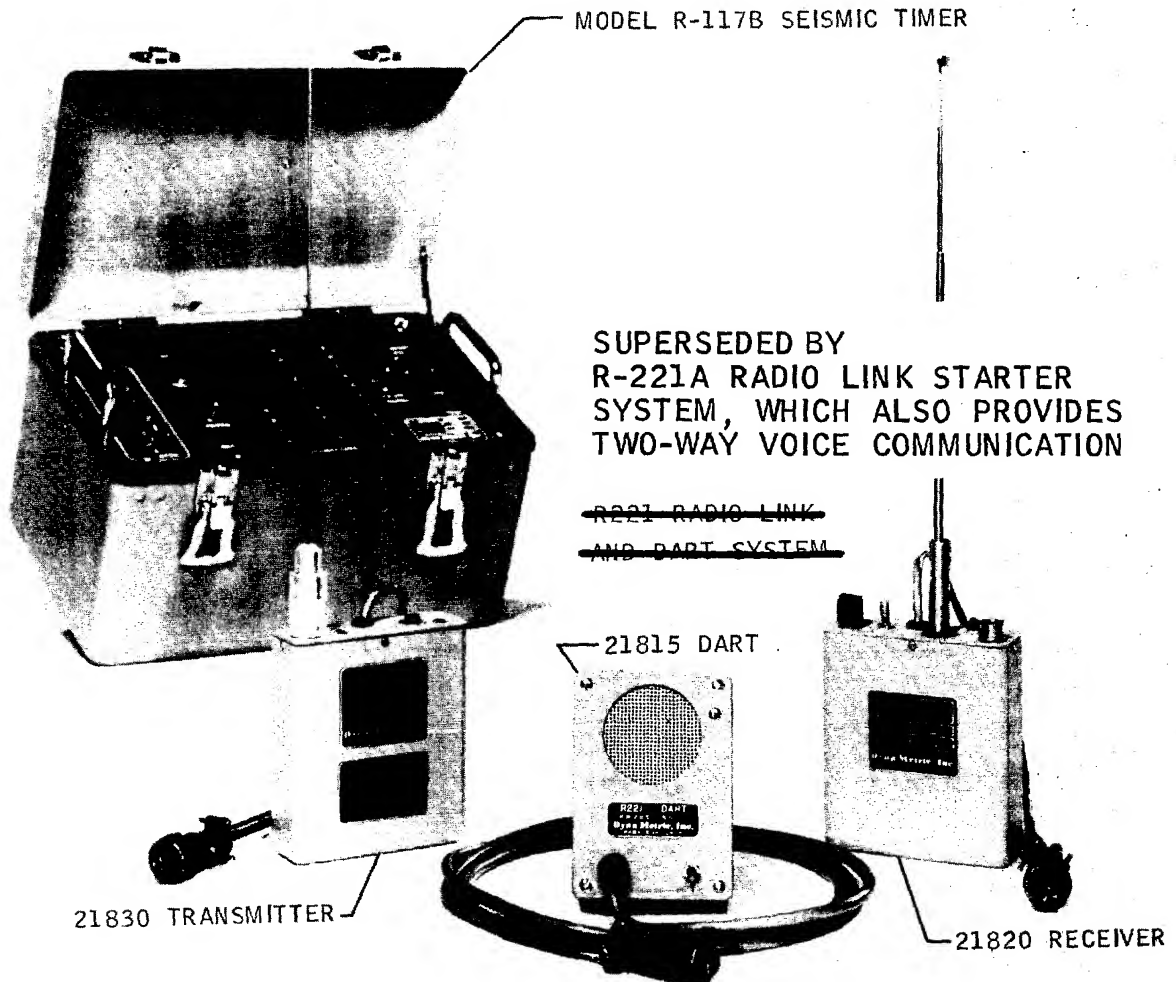


Figure 11-40.—R221 Radio link and dart system with R-117B seismic timer. 82.199X

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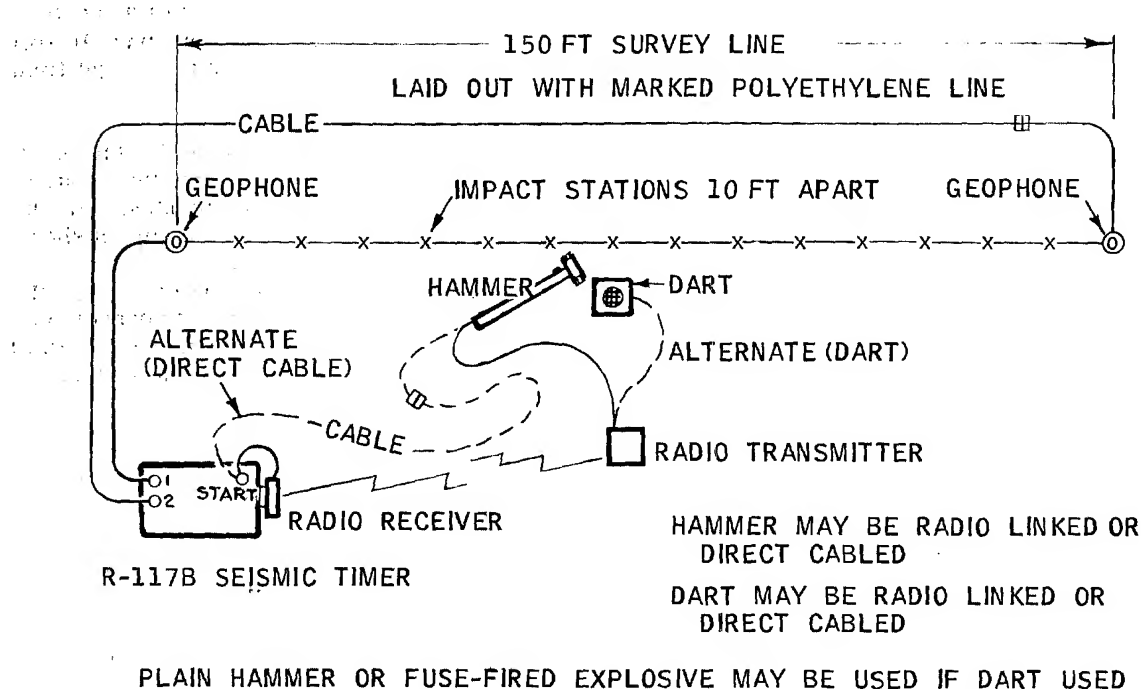


Figure 11-41.—Field set-up for 150-foot, double-headed seismic survey line.

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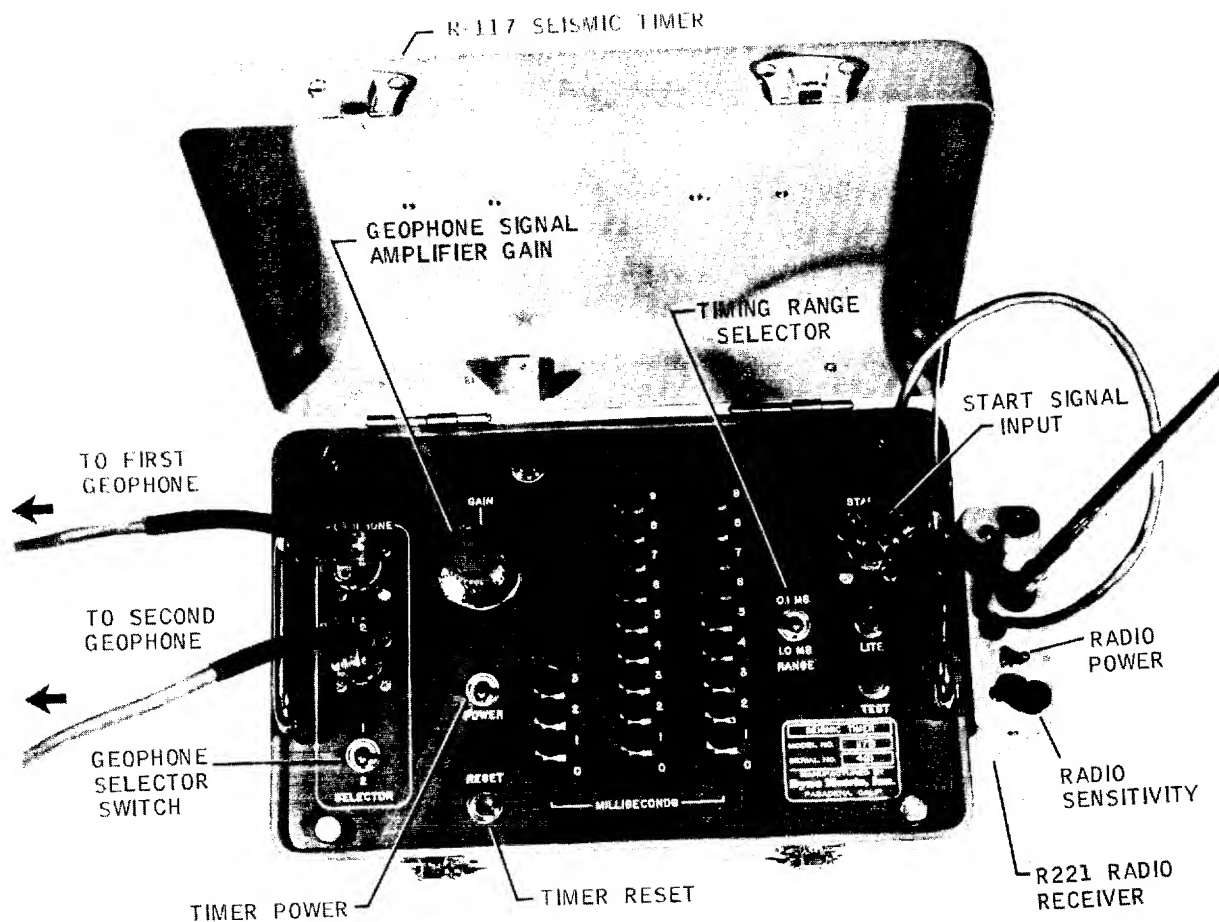
instruction manual. The work will proceed faster if the radio link is available, since the hammer man is free to move without dragging the long hammer cable. For the impact start signal, either the shock switch on the sledge hammer can be used, or a plain hammer can be used with the DART pickup of the radio link system. The DART is worn clipped to the impact man's belt. It "hears" the hammer below and sends the start signal to the timer, either through direct cable or over the radio link system. The hammer man should position himself for each blow so that the DART is always the same distance from the strike plate, within a few inches. This makes the start time uniform from blow to blow, within one millisecond.

(e) The control panel of the R-117B Seismic Timer is shown in figure 11-42 with the R221 Radio Link Receiver attached and connected to the START input of the timer. When the Radio Link is not used, the long hammer cable is connected to the START input. To begin the survey, turn the instrument POWER switch ON. Press the RESET button and note

that the time lights indicate 0-0-0 milliseconds. The RANGE switch should be on 1.0 MILLI-SECONDS for normal surveying. Turn the GAIN control to a low value. Press the TEST button and note that the timer starts counting (lights flickering). Now turn up the GAIN until the timer is stopped by the seismic BACKGROUND noise. This is the normal disturbance in the ground being received by the geophone. No one should walk or move near a geophone during the testing or surveying. After finding the GAIN setting at which the timer will count for several cycles without being stopped by background noise, reset the timer and proceed with the survey.

(f) The hammer man places the strike plate on a cleared ground surface at the first station mark on the yellow survey line. He taps it firmly with the sledge hammer to set the plate. With the timer geophone selector switch on GEOPHONE 1, the instrumentman then takes several travel-time readings from impacts at the first station, and plots the most REPEATABLE readings on his data sheet. He then places the geophone selector switch on GEOPHONE 2, and takes several time readings to the far

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Figure 11-42.—Control panel of R-117B seismic timer, with radio receiver and geophone cables attached.

geophone, plotting the most repeatable time also at station 10-ft on his data sheet (since this is the 140-ft station for the reverse line).

(g) The hammer man then proceeds to each impact station in turn along the line, and the procedure is repeated, until the complete forward all reverse travel-time graphs are plotted, as shown in figure 11-38.

Constructing the Soil Profile

In the office, the seismic survey data, topographic data, and other information from surface sampling and preliminary test borings are combined on the SOIL PROFILE SHEET. The lower part of this continuous roll paper

has the same 10 x 10 graph markings as the seismic field data sheet. The upper half of the paper is plain, for drawing the profile. The seismic travel-time graphs are replotted, and the necessary interpretations and depth determinations are made directly on the sheet. The soil profile is drawn above, with notations of all correlating information. A portion of a soil profile sheet is shown in figure 11-43.

In determining depths to subsurface layers for plotting on the solid profile, use is made of the MULTIPLE STRATA DEPTH CALCULATOR, PN 11786, furnished with the seismic timer. The two sides of this depth calculator are shown in figure 11-44 and 11-45. Instructions for its use appear on the calculator. A

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sample depth determination is shown on the soil profile (fig. 11-43.)

ADDITIONAL SEISMIC SURVEY TECHNIQUES

The seismic timer instruction manual gives methods for handling a large variety of possible field situations, including the determination of apparent dip, true dip and strike of subsurface strata, and so on. Two additional techniques should be mentioned here for information of supervisory personnel.

High-Speed Surveys on Outcrops

Quite often, when examining the area to be surveyed, a number of outcrops of rock or bedded materials will be observed, particularly when adjacent to hills or canyon walls. Usually, similar materials will be encountered beneath the soil cover during the regular seismic surveys. In such cases, the outcrops should be examined by conducting a very short seismic survey directly on the outcrop material. For this purpose, the seismic timer (fig. 11-42) has a high-speed range (RANGE switch at 0.1 MILLISECOND). In this range the timer counts in tenths of milliseconds, up to 39.9 milliseconds. The impact stations along the survey line should be one foot apart. On the travel-time graph, a ten-times expanded scale (1-inch = 1 foot, or 1 millisecond) is used. The resulting seismic survey will give the velocity in the outcrop material. If the material is weathered for a depth of a few feet, this depth of weathering will appear on the graph, and the velocity in the deeper, unweathered material will appear as a velocity in a second layer.

NOTE

The geophone can be coupled to a rock outcrop by using a large wad of modeling clay. Press the clay firmly against the rock and press the geophone spike firmly into the clay wad. Be sure to keep the geophone body vertical.

The information from outcrop surveys is of great value when interpreting the results of regular seismic surveys in the deeper soil areas, since the characteristic velocity of the bedded material will permit its identification on the regular survey lines. See the outcrop checks at the Quarry site, figure 11-39.

Seismic Surveys Beyond Sledge Hammer Range

In some cases, the work may require information about depths so great that useful data cannot be obtained with the available energy of the sledge hammer impacts. With the R221 Radio Link and Dart, the hammer survey line can be extended, using small fuse-fired explosive charges. When the last station where the hammer blow still gives first-arrival travel times is reached, a charge is set off. Its travel time is correlated with the hammer blow travel time (it will usually be shorter than the hammer time since much more energy is available and produces a higher-amplitude wave form, although the velocity is the same). The survey line is then continued, using the small fuse-fired charges at 50-foot intervals. When a time reading is questionable, the shot should be repeated, the confirmation.

The proper procedure for setting off the charges is as follows. At the impact point, drive a 3/4-inch diameter steel pipe or rod into the ground about one foot. Work the pipe back and forth slightly and withdraw it from the ground, leaving a hole for the charge. The charge will not be effective if fired on ground surface. Drop the charge in the hole, leaving its fuse extending above ground. Place the DART on the ground, microphone up, exactly four feet from the shot hole in any direction. Light the fuse with a burning punk. Step away at least 15 feet and wait for the shot to fire.

WARNING

If for any reason, the charge does not fire, wait for at least 30 seconds. Then cautiously approach the shot hole, keeping the face averted, and place a shovel full of loose dirt over the shot hole. Later, at a safe time, the charge can be dug up and examined.

Note, however, that this is a small explosive charge and will do no particular damage, other than that of a firecracker. While some degree of caution is needed, precautions observed in the handling of large explosive charges do not apply. (A large explosive charge would be harmful to equipment, as well as require special handling.)

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NOTE

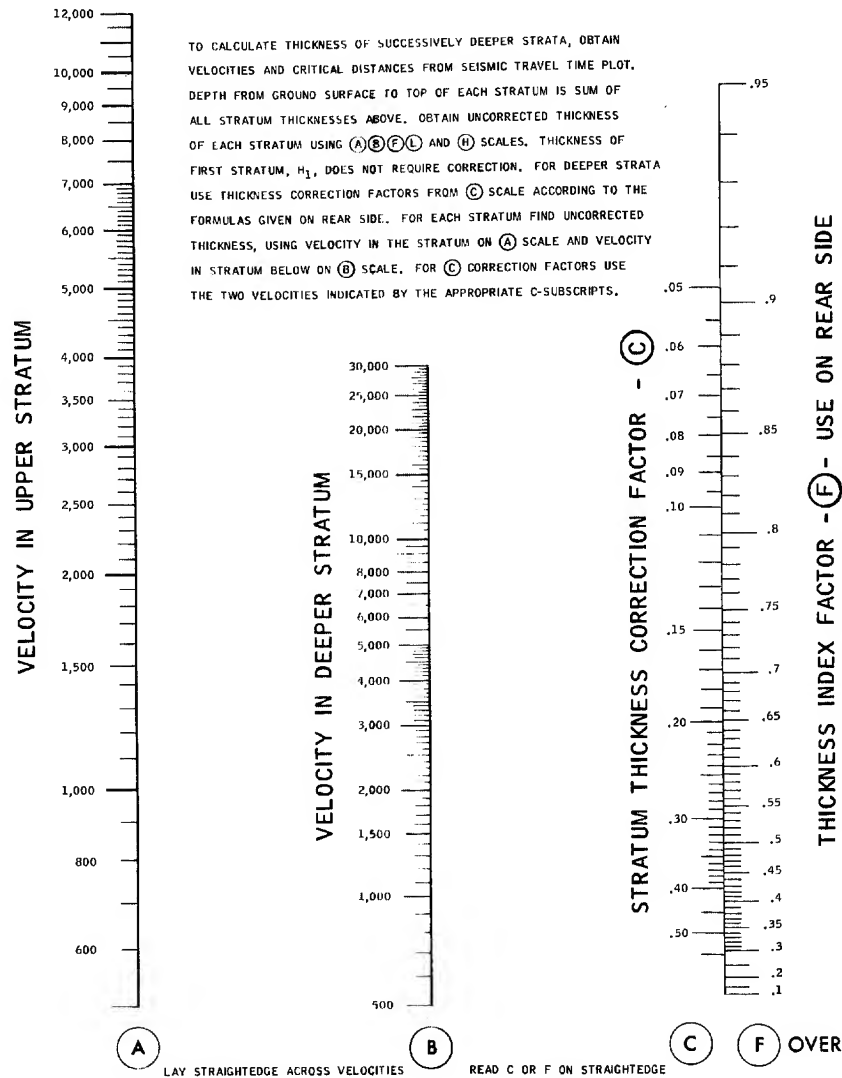
When lighting the charge, be careful not to make a loud noise or step near the DART, producing a premature start

signal for the timer. The instrument-man should be watching, and make sure the timer is properly reset at 0-0-0 immediately before the shot fires.

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MULTIPLE STRATA Depth Calculator

Part No. 11786

**DynaMetric, Inc.**
 330 WEST HOLLY STREET
 PASADENA, CALIFORNIA 91103
 PHONE . . . CODE 213-449-4300
 CABLE . . . DMI, PASADENA, CALIFORNIA

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PRICE \$ 4.00

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Figure 11-44.—Multiple strata depth calculator, PN 11786, front.

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| STRATUM | BASIC FORMULA FOR THICKNESS | CALCULATOR EQUIVALENT THICKNESS | DEPTH TO HORIZON |
|---------|---|--|---------------------------------------|
| 1 | $T_1 = \frac{L_1}{2} \sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$ | $T_1 = H_1$ | $D_1 = T_1$ |
| 2 | $T_2 = \frac{L_2}{2} \sqrt{\frac{V_3 - V_2}{V_3 + V_2}} - C_{1-2} T_1$ | $T_2 = H_2 - C_{1-2} T_1$ | $D_2 = T_1 + T_2$ |
| 3 | $T_3 = \frac{L_3}{2} \sqrt{\frac{V_4 - V_3}{V_4 + V_3}} - C_{2-3} T_2 - C_{1-3} T_1$ | $T_3 = H_3 - C_{2-3} T_2 - C_{1-3} T_1$ | $D_3 = T_1 + T_2 + T_3$ |
| n | $T_n = \frac{L_n}{2} \sqrt{\frac{V_{n+1} - V_n}{V_{n+1} + V_n}} - \sum_{r=1}^{n-1} C_{r-n} T_r$ | $T_n = H_n - \text{Sum of (n-1) correction terms}$ | $D_n = T_1 + T_2 + T_3 + \dots + T_n$ |

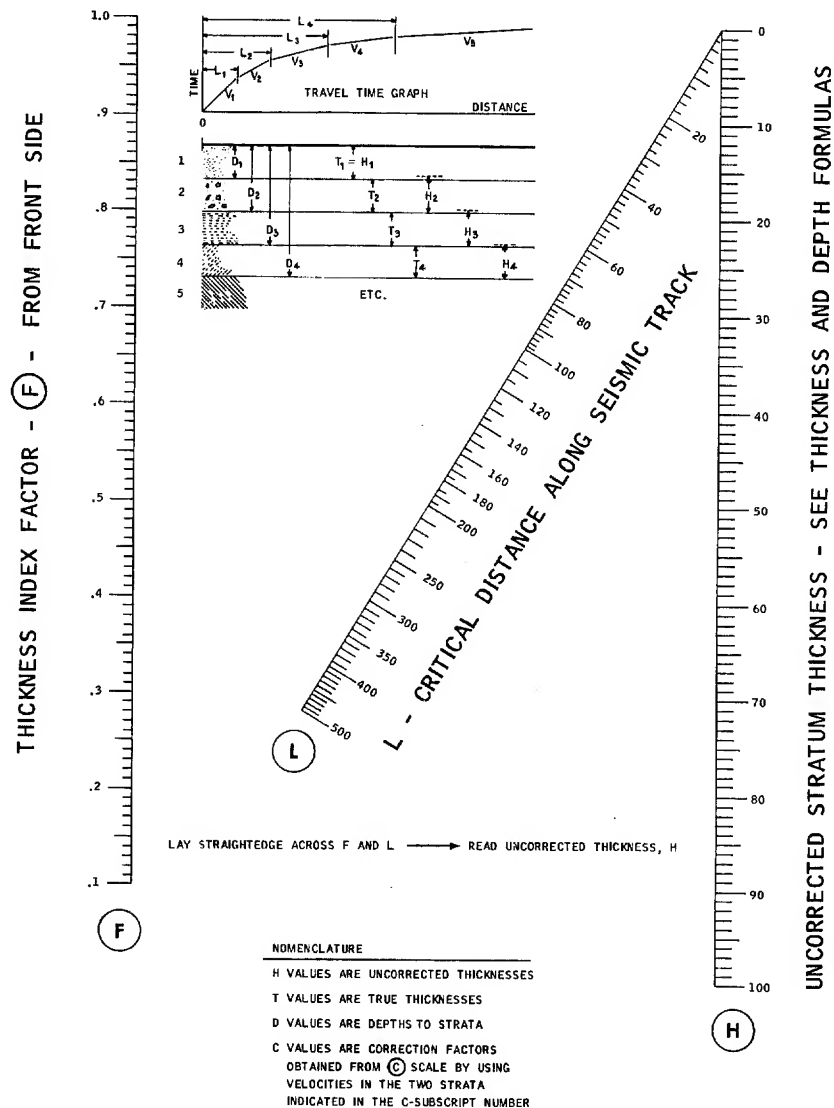


Figure 11-45.—Multiple strata depth calculator, PN 11786, back.

82.204X